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USE OF QUADTREES
FOR IMAGE SEGMENTATION

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ABSTRACT

The usefulness for image segmentation of a quadtree approximation of a $2^n x 2^n$ gray level image is examined. Estimates of the thresholds i defining object regions R^i in an image are obtained by analyzing the histogram of an image reconstructed from the quadtree. This information is used with the quadtree data structure to find the approximate location of the R^i within the image. A separate local threshold j to extract each R^i is then calculated from a histogram of those areas in the original image that are known to be in the vicinity of R^i. The threshold j is then applied to the original image locally in the vicinity of R^i to yield a region R^i_j similar to R^i. The procedure is then repeated for other thresholds $i \pm \alpha$, where α is a small interval, to yield regions R^i_k $(k = i-\alpha, i, i+\alpha)$ similar to R^i. The best R^i_k is chosen by correlating each one with an edge map of the original image.

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1. Introduction

Image segmentation is one of the basic tasks in image analysis. If regions in an image can be identified, their properties and the relationships between the regions can be studied. This can perhaps lead to the identification of the objects depicted in the image. Examples of images that consist of regions and where segmentation would be useful occur in cell classification, military target identification, and industrial parts inspection.

Segmentation methods for images that fall into the above classes are well known [1]. Many of these are based on using thresholding and edge detection to provide independent sources of information to select regions in an image. Milgram [2] discusses several objections to such methods and proposes an approach to segmentation based on correlating regions extracted by multiple thresholding of the image with an edge map of the image. A criticism of this method is that if the image and its edge map are noisy, as is the case in many practical applications, the correlation of a region extracted by thresholding using the best possible threshold may not be as good as that for regions extracted by other less suitable thresholds.

This paper examines an approach to image segmentation based on using a quadtree approximation image [3] to identify regions in the image. The advantages of this approach are firstly that

noise points are not present in the quadtree approximation of an image and secondly that by traversal of the tree it is possible to find the approximate location of the regions within an image. It is thus possible to extract a region by applying thresholds in the vicinity of the region and to identify the best threshold by correlating the extracted region with an edge map of the original image. Since thresholds to extract regions are applied locally, noise points which may be present elsewhere in the edge map have no effect on the correlation of extracted regions to the edge map of the original image.

2. Representation of an image by a quadtree

A $2^n x 2^n$ binary image can be represented by a quadtree by successively dividing it into four quadrants. Quadrants which contain both black and white areas give rise to branch or "gray" nodes in the tree, while those which are either all black or all white are black or white leaf nodes and are not further subdivided. A quadtree representation is useful, for example, for the approximation of shapes [4]. Of the several kinds of approximations possible, the one using the concept of a <u>maximal node</u> is perhaps the most useful. A maximal node (or block) is a node which has no adjacent nodes of greater size.

A quadtree can also be used to approximate a $2^n x 2^n$ gray level image. In this case quadrants through which edges pass, or that have a busy texture, will correspond to branch nodes in the tree, while those that are sufficiently homogeneous will be represented by leaf nodes. The measure of homogeneity used for classifying a particular quadrant as a leaf or branch is important not only for the size of the tree but also for the quality of the image when it is reconstructed from the tree. If the measure is too strict, the size of the tree will be prohibitively large, whereas if it is too loose, the quality of the reconstructed "q-image" will be poor. For a discussion of different measures of homogeneity and their effects on the size of the resulting quadtree and the quality of the corresponding q-images, see [5].

The concept of maximal nodes can also be extended to quadtree approximations of $2^n x 2^n$ gray level images. In this case a maximal node is defined as a node which has no adjacent nodes of greater size with similar gray levels. The following section examines some properties of a quadtree approximation of a $2^n x 2^n$ gray level image.

3. Properties of the q-image

In a quadtree approximation of a $2^n x 2^n$ gray level image, leaf nodes in the tree correspond to blocks of approximately constant gray level in the q-image. The q-image has several properties which are useful for image segmentation.

Firstly, large blocks in the q-image characterize areas in the original image that are reasonably homogeneous, while small blocks are characteristic of areas that have a busy texture or which lie on or near region boundaries.

Secondly, parts of such small regions tend to be "absorbed" by the large blocks in the q-image--for example, this occurs if a large proportion of a block in the original image is homogeneous and a much smaller part, usually near one of the block boundaries, is busy. Since the gray level of a block in the q-image is the average gray level of the corresponding block in the original image, the effect of such absorption on the q-image is to increase the number of points with gray level equal to those of large leaves and decrease the number of those with gray levels equal to those of small ones. This is reflected in the histogram of the q-image in which peaks corresponding to large homogeneous regions are enhanced with respect to those in the histogram of the original image. Thus the valleys in the q-image histogram are likely to yield more accurate thresholds for separating regions in the original image than those obtainable from the histogram of the original image. The enhancement

of peaks in the histogram is further improved if the histogram is compiled from only those points which lie within maximal blocks of the q-image. Figure 1(a) shows the image of a tank and Figure 1(b) shows its corresponding q-image. Figure 1(c) shows the maximal block approximation to Figure 1(a). Figures 2(a), 2(b), and 2(c) show the histograms corresponding to the images in Figure 1. Note that the enhancement of the peaks is significant in Figure 2(b) and even more improved in Figure 2(c). Another approach to enhance peaks is to suppress small blocks entirely from the q-image [6]. This process is essentially equivalent to that described in [7]. It follows from the observation that an estimate of the threshold separating regions is obtainable from the histogram of values on either side of the edges between the regions. (See also [8].)

A third useful property of the q-image is that those edges that are strong in the original image tend to be enhanced, while those that are weak tend to be suppressed. This is because the reasonably homogeneous regions which can be expected to contain the weak edges correspond to leaf nodes of approximately constant gray level. The use of edge information in the q-image to enhance edges obtained by applying an edge operator to the original image is described in [9]. The importance for the segmentation procedure of a clean edge map is discussed below.

4. Segmentation by applying quadtree-directed local thresholds

The preceding section showed that good estimates of the thresholds separating regions in the original image can be obtained from a histogram of its corresponding q-image. If such a threshold is applied to the original image it is likely that isolated noise points or small noisy areas will survive. Noise points in the original image can be eliminated by smoothing this image, for example, by applying a median filter. Small noisy areas in the thresholded image can be removed by finding the number of connected components in this image and retaining only the large ones, since these are most likely to correspond to actual regions in the original image [2]. An objection to this technique is that the definition of a "large" component is arbitrary, although it could perhaps be defined using prior knowledge of the image environment.

Connected component analysis is not required, however, if the thresholds for extracting n object regions suggested by analysis of the q-image histogram, say Q_0^i $(i=1,2,...,n)$, are applied locally in the vicinity of these regions. Suppose that an image consists of one object region and Q_0^1 is the estimate of the threshold separating it from the background in the image. The quadtree approximation of the original image can be used to identify the approximate location of this region, say R^1 in this image, since by traversing the tree it is possible to find the position in the image of the block corresponding to any node in the tree. Thus the region R^1 is located in the vicinity

of blocks corresponding to those nodes in the tree whose gray level is greater than Q_0^1. Let N_k^1 (k=1,2,...,m) be the m nodes with gray levels above Q_0^1. From the preceding discussion it should be evident that if Q_0^1 is applied locally in the vicinity of blocks corresponding to N_k^1, the extracted region, say R_0^1, should closely resemble R^1. It is possible, though, that there is another threshold near Q_0^1, say Q_{01}^1, which when applied locally in the vicinity of blocks corresponding to N_k^1, will yield a region R_{01}^1 which has a better resemblance to R^1 than R_0^1. This threshold, Q_{01}^1, can be obtained by computing the histogram of the area in the original image which lies in the vicinity of N_k^1. Such a histogram would have a large peak corresponding to points within R^1, and a smaller peak (a "shoulder") corresponding to points just outside R^1. The bottom of the valley between these two peaks corresponds to the threshold Q_{01}^1.

The success of the procedure for extracting R^1 described in the preceding paragraph depends to a large extent on the accuracy of the initial estimate Q_0^1 (see [10]). In practice the initial estimate Q_0^1 may not be accurate, so that other thresholds near Q_0^1, Q_k^1, leading to extracted regions R_{kl}^1, must be examined. In order to find the best thresholds for extracting R^1, it is therefore necessary to correlate each extracted region R_{kl}^1 with an edge map of the original image. Since each R_{kl}^1 is approximately in the same location in the original image, noise

points which may be present elsewhere in the edge map will have no effect on these correlations. However, edges near the boundaries of R^1 may be noisy and therefore it is appropriate to use an edge map from which most of the noise has been removed by a technique such as that described in [9]. The above discussion can easily be generalized to an image containing more than one object region.

5. Segmentation algorithm

The segmentation procedure discussed in Section 4 can be summarized as follows.

1. Using a suitable measure for the homogeneity of a block, construct a quadtree approximation of the original image. From the quadtree reconstruct the approximated original image (the "q-image").
2. Histogram the q-image and from this histogram estimate the thresholds Q_0^i (i=1,2,...,n) which separate the n regions in the image, R^i (i=1,2,...,n)
3. For each Q_0^i do steps 4-6.
4. By traversing the quadtree identify the nodes N_k^i whose gray levels are above Q_0^i. Compute a histogram of those areas in the original image that are in the vicinity of N_k^i.
5. From the histogram computed in Step 4, find the threshold Q_{01}^i. Apply this threshold to the original image in the vicinity of N_k^i and extract the region R_{kl}^i.
6. Repeat steps 4 and 5 for other thresholds $Q_0^i \pm \alpha$, where α = 1,2,3, say. Correlate the extracted regions R_{kl}^i with an edge map of the original image. The region R_{kl}^i with the best correlation is the region R^i in the original image.

Note that in Step 2, the histogram of the q-image can be computed directly from the quadtree. The thresholds $Q_0^i \pm \alpha$ will,

in general, be distinct from Q_0^{i+1} and Q_0^{i-1} since the difference in gray levels of the various regions is significant in the image classes under study.

6. Examples

Figure 3 shows the various stages of applying the segmentation algorithm described above to the image of a tank in Figure 1(a). Figure 3(a) shows the edge map obtained by applying the Prewitt edge operator to the image in Figure 1(a). Figure 3(b) shows the result when this edge map is cleaned according to the procedure described in [9]. Note that a large number of the noise edges have been suppressed. Figure 3(c) shows blocks in the q-image corresponding to the nodes N_k^1. Note that the blocks do not completely contain the tank. Figures 3(d)-3(f) show the extracted regions R_k^1, when the thresholds Q_k^1 are $Q_1^1 = 24$, $Q_2^1 = 25$, $Q_3^1 = 26$. Correlation of these regions with the edge map in Figure 3(c) identifies Q_1^1 as the best threshold for extracting the tank from the background.

Figures 4 and 5 show the results of applying the segmentation procedure to the image of a blood cell which contains two object regions. Figure 4a shows the original image and Figure 4(b) shows its corresponding q-image. Figures 4(c) and 4(d) show the histograms of the images in 4(a) and 4(b) respectively. Note that the peaks in the histogram of the of 4(d) are more enhanced than those of the histogram of Figure 4(c). This shows that the smoothing implicit in the q-image, which perhaps appears subjectively excessive, is useful for segmentation since a better estimate of a threshold separating regions can

be obtained from the q-image histogram than that obtainable from a histogram of the original image. Figures 5(a)-5(c) show the extracted regions R^1_{kl} for the thresholds $Q^1_1 = 4$, $Q^1_2 = 5$, and $Q^1_3 = 6$. Figures 5(d)-5(f) show the extracted regions R^2_{kl} for the thresholds $Q^2_1 = 19$, $Q^2_2 = 20$, $Q^2_3 = 21$. Correlation of these regions with an edge map of the image in Figure 4(a) identifies Q^1_3 and Q^2_2 as the best thresholds for separating the regions in the image. Figure 5(g) shows the segmented image.

7. Conclusion

This paper has shown that the quadtree approximation of an image is useful for segmentation of the image. The histogram of the image reconstructed from the quadtree can be used to give good estimates of the thresholds separating object regions in the image. The quadtree data structure can be used with this information to find the approximate location of the regions within the image. Each object region can then be extracted by applying a separate local threshold calculated from a histogram of those areas in the original image that are known to be in the vicinity of the object regions in the image. The extracted regions are correlated with an edge map of the image and this correlation is used to define the best segmentation of the image. No prior knowledge of the image environment is required.

Figure 1

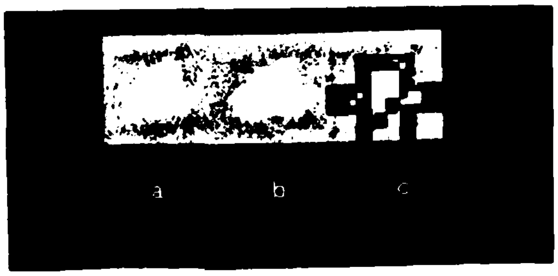


Figure 2

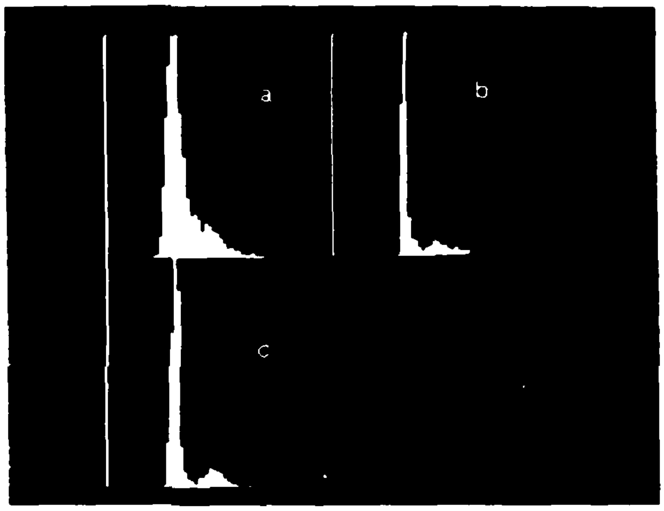


Figure 3

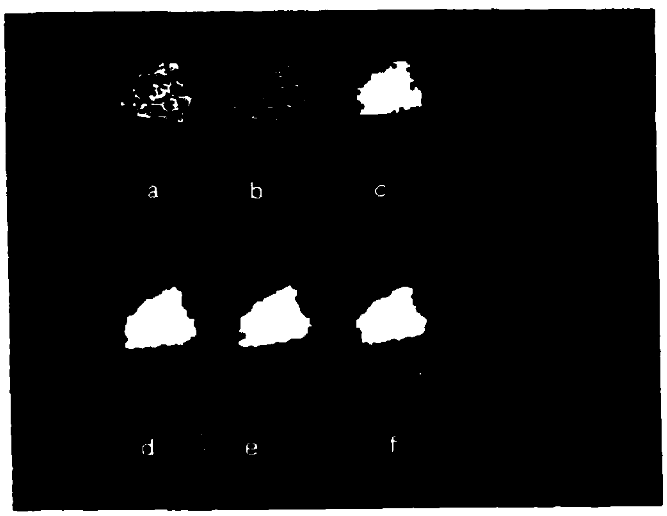
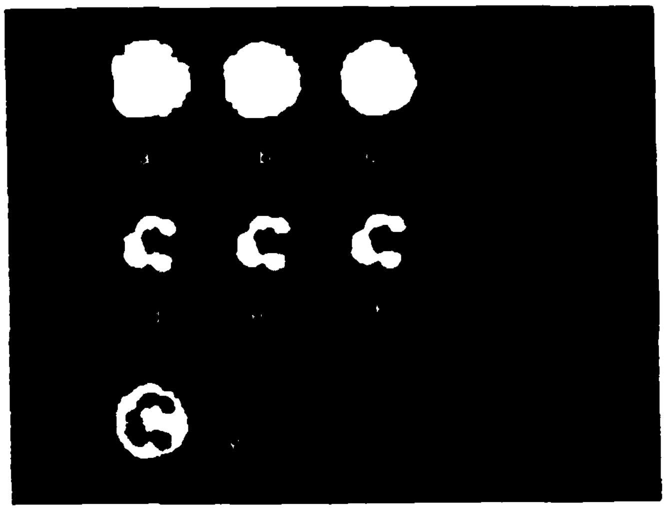


Figure 4

Figure 5



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